FENIX 2.0

TEAM CHILE / USM

JURY NARRATIVES
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UNIVERSIDAD TÉCNICA FEDERICO SANTA MARÍA

Valparaíso, Chile.

U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON 2020

Engineering Jury Narrative

1.2.1 Requirements-Based Design Approach:

Whether working on a small or big project, defining the project's requirements is a dynamic and critical task. Requirements are the list of functions, capabilities or necessary features that you must have and the plan to create them. A requirement is the condition or capacity that a system, product, service or component must have to satisfy a contract, standard, specification, or other formally established documents. In our case, we have started the definition of a requirements model to help us identify, based on a formal method, which are the important functionalities that our Casa Fenix 2.0 proposal will fulfill.

Requirements must be defined in the initial phase together with the stakeholders involved to obtain a complete and shared vision of all the pieces and be able to prioritize based on the objectives of the project. In our methodology, the requirements do not tell you what design your product should have or how to develop it. They tell you what features and functions you expect it to have, and how users should interact with those features.

To define a meaningful set of requirements, it is recommended to use a descriptive statement that indicates each material and functional expectations for Casa Fenix 2.0, detailing them later on as they progress through the process and get feedback from the initial tests and prototypes. A requirement definition can be very complex, but it helps to make the project a success and not a waste of time and resources. Well-developed requirements for our project must comply with the following characteristics:

*They must be unique. The requirement can only be interpreted in one way.

*They must be specific. Do not mix 2 different requirements.

*They must be clear, complete and well defined.

*They must be viable (realistic and possible). It must be feasible according to the current restrictions of time, money and available resources.

*They must be consistent and prioritized based on the Casa FENIX 2.0 general objectives

*They must be able to be verified during prototypes and tests of individual parts and as a whole

*They must be necessary: A requirement is not necessary if none of the interested parties needs it, or if their withdrawal has no effect.

The requirements may even vary over time, because if the project is developed correctly, intermediate decisions or higher level of maturity in the project will results in changes of the initial requirement model. We have established an original set of requirements, but we expect this model to evolve as the project move forward. However, For this project, and based on a standard process modeling for requirements, we have divided our requirements in the following categories:

Industry Requirements

They define the objectives and problems that the team wants to solve with the Casa FENIX proposal. They must be based on a real need of the intended user of the dwelling unit.

User Requirements

They describe the expectations of the users of the dwelling unit and how these users will interact with the final product. These kind of requirements show techniques of stakeholders data gathering, scenarios and possible customers focus groups to help define the functions, tasks and characteristics for the developed dwelling. All this information will be important for the definition of design specifications further down the design process.

Quality Requirements

They detail the characteristics that our proposal must have to maintain its effectiveness and anticipate possible problems and limitations. For instance, energy performance and manufacturing quality for on-site assembling will be closely and continuously assessed by our team. In terms of user experience, if the quality of Casa FENIX 2.0 does not match the expectations that the user has about it, it will not work

Implementation Requirements

They are used to detail changes in the design and construction processes, roles in the team, migrations from one method to another, or any other disturbance that occurs during the design and constructions phases.

Functional Requirements

Due to their relevance for Casa FENIX 2.0, we have left this kind of requirements as our last one. Functional requirements will provide details of how the Casa Metamorfosis should behave and specify what is needed for its development and construction. Functional requirements are critical. Thus, here we further extend the explanation of this category:

*They express the capabilities or qualities that Casa FENIX 2.0 must have to satisfy All the requirements of the project stakeholders.

*They are expressed in terms of what the behavior and benchmarks of Casa FENIX 2.0 should be and what are the methods to assess the completeness of such behaviors.

*They must provide a sufficiently detailed description to allow the different technical solutions of Casa FENIX 2.0 to be developed and implemented.

*They are the ones that most influence whether our project will be accepted or not by the end users.

Functional Requirements Lifecycle Methods that the Team Chile Intends to Use

We pretend to use methodologies that establish a flexible approach to manage functional requirements. We expect the project to be executed in short design iterations and with a greater constant interaction between the design team and the consulting experts, embracing the change instead of rejecting it.

For this methodology, we propose that the project leader together with the System Integrator are the ones responsible for managing all functional requirements. The project leader and the System Integrator hold meetings with all stakeholders and identifies the functional requirements which then lead to the design team for their specification and fine-tuning.

For meetings with stakeholders, it is also possible to apply requirements-raising techniques, such as interviews, work tables, among others so that the entire design team can be part of it.

One of the good ways to document the functional requirements in our methodologies is a storyboard of a real (or fictional) user to define the functional and material characteristics of the intended design. This agile approach encourages constant communication between stakeholders, design team, and users. Thus, functional requirements are progressively developed, prioritizing for development those that are unambiguously defined and agreed by everybody.

Functional Requirements Management

An aspect that is essential to understand when defining a functional requirement is the management of it does not end when they are identified, analyzed and documented. Casa FENIX 2.0 requirements management extends throughout the entire design and construction of the project, and even transcends it.

The Business Analysis Body of Knowledge (BABOK) guide in its version 3, defines the activities involved in the management of requirements, namely:

*Traceability of requirements.
*Maintenance of requirements.
*Prioritization of requirements.
*Evaluation of changes in requirements.
*Approval of requirements.

In predictive approaches to project management related to software development, for example, requirements management is a specialty, composed of functional requirements management and business analysts. Prioritization and approval are part of the planning process and changes in requirements are processed using a scope change process or methodology.

On the other hand, our methodologies integrate the management of requirements within the design approach and activities. For example, the prioritization of requirements will occur naturally by managing a design activities accumulation and interaction (typical of architecture designers), which is prioritized according to the progress of the development of functional requirements and its value to the project. The evaluation of changes to the requirements will be done using a "Sprint Review" method in meetings that occur at the end of each project delivery iteration.

1.2.2 Engineering Concepts and Design Methods to Implement in Casa FENIX 2.0.

Reconfigurable Manufacturing Systems (RMS) and Robotic Manufacturing: The key for Mass Customization.

Timber Joinery Robotics (Carpintería de Armar Robotizada CAR). Is a CAD/CAM and engineering wood construction technique, using industrial robotics manufacturing and manual assembly for a timber-framed house. This technique offers a value proposition based on the prefabrication of wood framing with woodworking joints (joinery) of complex geometry, capable of being assembled, disassembled and reconfigured over time according to different needs and opportunities of occupants. It is based on the methods and philosophy of Mass Customization and Flexible Manufacturing Systems. In this section we introduce the concepts behind this approach and give examples based on similar material systems and experiences.

Dedicated manufacturing Systems (DMS)

The predominant approach for mass production of constructions components is called Dedicated Manufacturing Systems (DMS). Dedicated manufacturing systems, e.g., mass or batch production systems, are characterized by rigid equipment designed specifically for a single product configuration . They provide high production rates and low product flexibility, and are expensive to change with tooling cost ranging from \$70k-\$200k and 3+ months lead times for new tooling. Batch production is commonly scheduled months in advance of product delivery and is well suited for off-shore production as can be seen in the majority of products sold in the world today.

For example, in the Photovoltaics domain, current prices for racking systems for commercial roofs range from \$0.16-0.20+ per Wdc in the United States. These systems tend to utilize dedicated manufacturing equipment for one size fits all configurations with limited variability to adjust tilt angles, PV panel sizes, and specific environmental demands. Manufacturers who maintain a portfolio of systems that serve segmented applications have reported excessive overhead cost and have moved towards consolidated offerings .This happen in sheet metal manufacturing but also in other industries such as wooden products, which are important for our project. However, to stay competitive, manufacturing companies must use systems that not only produce their goods with high productivity, but also allow for rapid response to market changes and specific consumer needs. This last condition is one the premises of the development of Casa FENIX 2.0 at the functional level, but also at the production level. We would like to design construction systems that can actually rapidly respond to requirements or market changes. The following figure shows an example of Dedicated Tooling in the Sheet Metal domain.

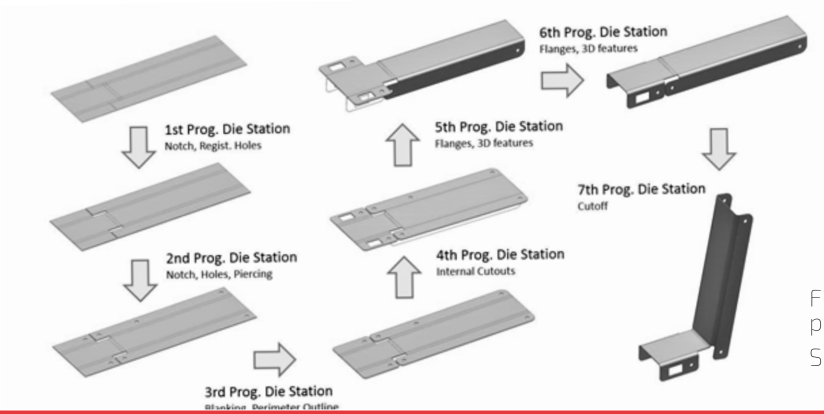


Figure 01, Conventional Progressive Stamping Approach with Dedicated Tooling.
Source: Francisco

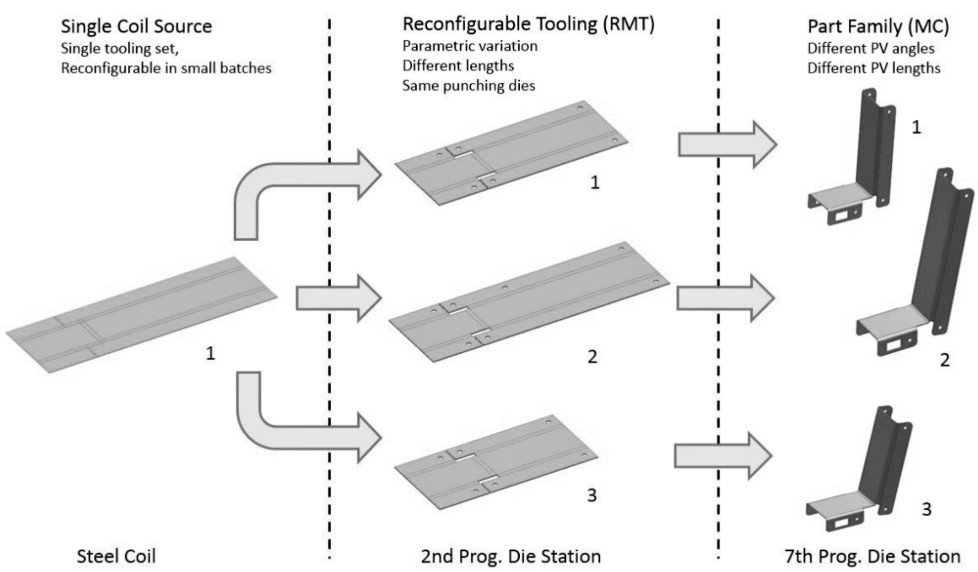
Mass Customization (MC) and |Flexible Manufacturing Systems (FMS)

Market competitiveness together with product flexibility, which is a pillar of our proposal, can be achieved through Mass Customization (MC). MC relates to the ability to provide customized products or services through flexible processes in high volumes and at reasonably low costs. One of the fundamental approaches to consolidate manufacturing for MC is through Flexible Manufacturing Systems (FMS). FMS consist of computer numerically controlled (CNC) machines and other programmable automation and can produce a variety of products on the same system. In our case, the robotic manufacturing approach developed at our school is a great example of a FMS. Because they do not use dedicated tooling, FMS systems are economical when the production volumes are low, and a large variety of parts are produced. Yet, FMSs do not provide the robustness of DMSs and often have wasted resources and long production time making them uneconomical in many production situations. Especially, when batches sizes go beyond prototype scales. This last part will not be the case for the present proposal. However, it's something we would like to keep in mind for possible further spin-offs and commercialization of our construction system.

Reconfigurable Manufacturing Systems (RMS) and Reconfigurable Machine Tools (RMT) Through Robotic Manufacturing.

A cost-effective response to rapid market changes and different customer needs requires a new manufacturing approach that not only combines the high throughput of DML with the flexibility of FMS, but also is able to react to changes quickly and efficiently. This situation led to the development of Reconfigurable Manufacturing Systems. A reconfigurable manufacturing system (RMS) is one designed at the outset for rapid change in its structure, as well as its hardware and software components, in order to quickly adjust its production capacity and functionality within a part family in response to specific customer needs or changes in the market. The Reconfigurable Manufacturing System (RMS) approach as well as one of its components – the Reconfigurable Machine Tool (RMT) were first developed in 1999 in the Engineering Research Center for Reconfigurable Manufacturing Systems (ERC/RMS (). The RMS goal is summarized by the statement – Exactly the capacity and functionality needed, exactly when needed.

Figure 02, Part Family Approach of RMT. Source: Francisco Valdes



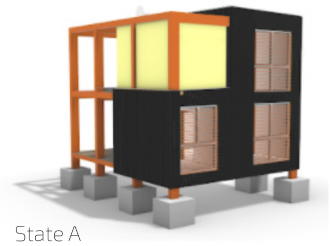
The RMS contains an economic equipment mix of flexible (e.g. CNC and Robotics) and reconfigurable machines with customized flexibility, such as Reconfigurable Machine Tools (RMT), and Reconfigurable Assembly Machines. RMT can then be designed to perform the necessary machining operations on all the members of the part family with reconfiguration to the machine tool itself. By contrast to conventional CNCs that are general–purpose machines, RMTs are designed for a specific, customized range of operation requirements and may be cost–effectively converted when the requirements change. In order to efficiently change the tooling configuration of RMT systems, control components with modular scalable capabilities are required. To achieve those characteristics, controllers for RMTs require open–architecture systems. In open–architecture control, the software architecture is modular and, thus, hardware components (e.g., encoder) and software components (e.g., axis control logic) can be easily added or removed, and the controller can be cost–effectively reconfigured. In our School, we have done extensive research on Flexible Manufacturing Systems for woodworking, using an industrial manipulator robot. This experience is part of the research project FONDECYT 1181015 and promotes the use of robotics for the development of structural and ornamental elements of complex geometry for the restoration and rehabilitation of the Chilean architectural heritage in wood. As it can be seen in the following table, for prototype development, and FMS/ Robotics approach seems the most feasible. However, for langer batches that require a degree of customization, RMS and RMT seem the best way to proceed.

	DMS	RMS/RMT	FMS/Robotics
System Structure	Fixed	Adjustable	Adjustable
Machine Structure	Fixed	Adjustable	Fixed
System Focus	Part	Part Family (feature based)	Prototype
Scalability	No	Yes	Yes
Flexibility	No	Customized	General Purpose
Simultaneous Operating Tool	Yes	Yes	No
Productivity	High	High	Low
Tooling Cost per Part n= Number of parts of a family	x	x/n	0
Tooling Cost per Part on a Family of "n" members	x*n (Very expensive)	x (Low cost over time)	Low cost
Part Cost Amortized tooling of a 4M Batch	High	Low (Family tooling)	Very High
Part Cost Amortized tooling of a 1MM Batch	Low	Low	Very High
Responsiveness to Components Changes	Slow	Fast	Fast (in very small batches)
Level of Customization (Low, Medium, High)	Low	Medium	High

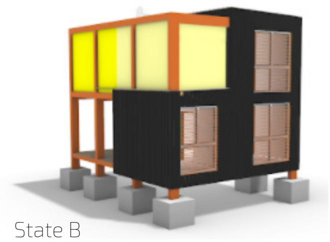
Table 01: Manufacturing Approaches Comparison

From Flexible Manufacturing to Flexible Design

At present
832.1 sqf



State A
951,5 sqf



State B
1073,1 sqf

State C
1195,8 sqf

Flexibility. The "Casa FENIX 2.0" proposes flexible unit typologies according to the occupant's family composition, which responds to the current lifestyle of families in Chile. Modern Chileans families are dynamic and diverse, which through their mutability over time, could inform and allow the metamorphosis of our proposal. This metamorphosis is manifested through the over-time transformation of the dwellings by means of flexible spaces that vary their shapes, orientation and even their usable surface by modifying the adjacent housing units. Thus, the users can intervene (extend or reduce) spaces of their homes depending on variations on the number of families on the life cycle of the house.

Flexible structure. To achieve this, it has a primary structural system that supports the metamorphosis of home units. This main structure is conceived with a public first floor of reinforced concrete on which the wooden seismic-proof structure of the four storeys is attached to. The wood structure is projected by a glued laminated posts and beams system constituting a reticle, inscribed within a mesh to modulate the operations of spatial variations. This 5x5m wooden grid is industrially manufactured through robotical parametric design (Timber Joinery Robotics) composed of linear components of glulam timber with robotically carved out joints. The floors, supported on the structure described above, are built of a five-layer CLT board, on which a top layer of a mortar slab is disposed. The spaces of homes are distributed according to the operations with as much flexibility as possible, excluding the humid, installations and general circulation zones, which are kept fixed on vertical volumetric bands. These 3D vertical components determine and limit the number of variations for space metamorphosis, they are prefabricated in a workshop and transported to site.

The Casa FENIX 2.0 dwelling develops a novel building system, which is not only fully made of timber structure and skins, but also innovates on mid-height timber structures for housing in Chile. The proposal uses engineered wood and a structural model based on robotic carpentry and complex-geometry joints. One of the main characteristics of the Casa FENIX 2.0, consists on the possibility of space transformations through the extraction of walls and / or slabs of the housing units. The construction system is designed in such a way that the primary and secondary structural subsystems work together to form an integrated structural system without the need of sacrificing the architecture and interior design of the dwelling units.

Based on these considerations, the total structural system is divided into 3 collaborative sub- systems:

1. PRIMARY STRUCTURE: This sub-system includes all main structural components of the building, which are based on the column/beam approach and it is specified on laminated engineered wood and robotically-made carpentry junctions. These components of the main structure subsystem will also undergo Finite Element Analysis testing in further stages of the project.

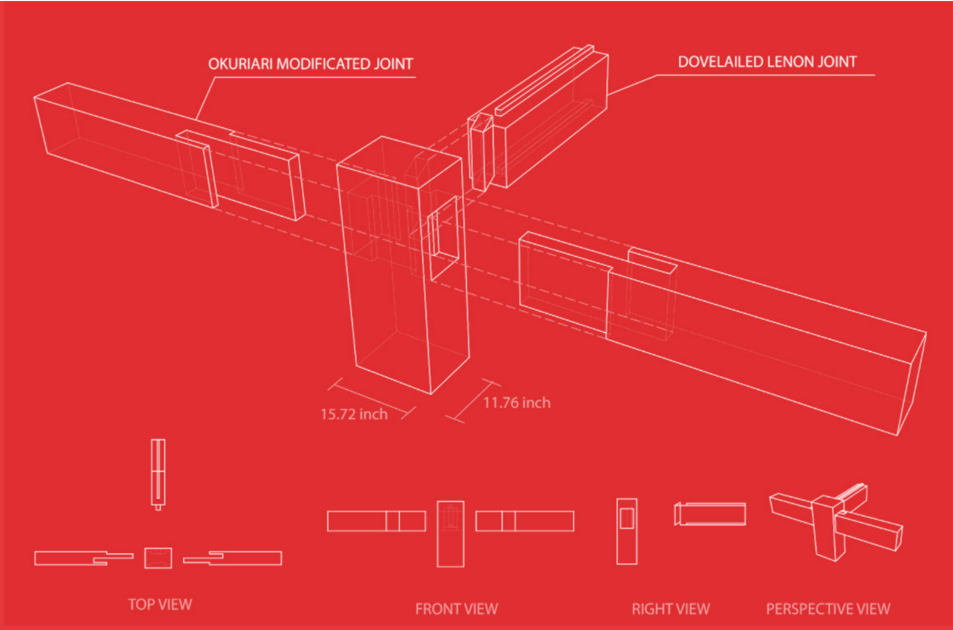


Figure 03: Central column union with 3 Beams. Primary Structure; Source: Team Chile

2. SECONDARY STRUCTURE: This sub-system includes all internal walls of the dwelling. This internal-walls system will be also developed based on complex-geometry carpentry joints made through robotic manufacturing. The system, besides its structural functions, will be designed so that it allows transformations of space and use, which is a fundamental requirement of the project (adaptable walls figure 08).

In addition, the system, because its modular configuration, will allow the exchange of individual parts without the need of disassembling the entire wall or structural sub-system.

These internal walls are specified as thinner sections of CLT and will have easy accessibility for replacement or modification.
To allow future space modifications of this flexible dwelling, 3 robotic carpentry joints are specified:

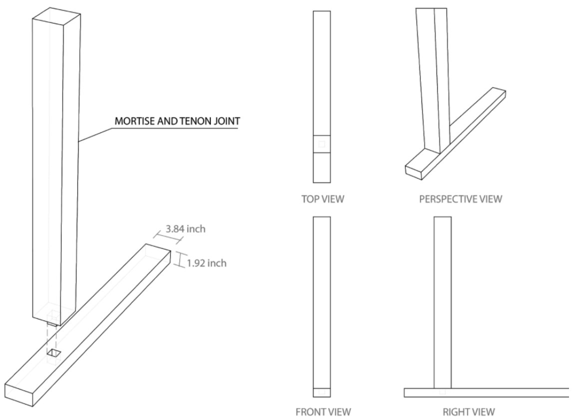


Figure 04: Robotic Carpentry joints from the Secondary Structure. Source: Team Chile

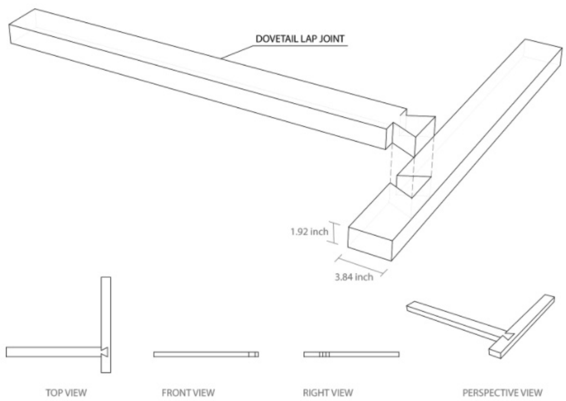


Figure 05: Robotic Carpentry joints from the Secondary Structure. Source: Team Chile

3. TERTIARY STRUCTURE: This sub-system includes all internal non-bearing walls of the dwelling. These kinds of walls are specified so that they can be removed at any moment, during construction or during use of the dwelling. These walls are designed as lightweight framing made of solid wood and their eventual removal will not require skilled labor.

The Walls. The fixed load-bearing walls will not suffer any change, or metamorphosis, over time. However, they have an essential function for the optimal operation of the structure (primary structure). These walls are mostly in the perimeter of the building so that they can prevent structural issues without damaging the architectural concept. As a secondary structure, there are adaptable walls, which are mostly in the perimeter of the first floor, wet zone and some walls of the facade. These walls are called "adaptable" because despite being fixed in the structure, their openings are reconfigurable, which allows a change at the spatial level of each housing unit, depending on the use and the number of spaces K that the house adopts. Finally the removable walls (non-structural), which adapt differently according to the type of wall they are linked to. These walls are partition walls and easy to move around so that families can change and reconfigure the spaces as they see fit within the K zone.

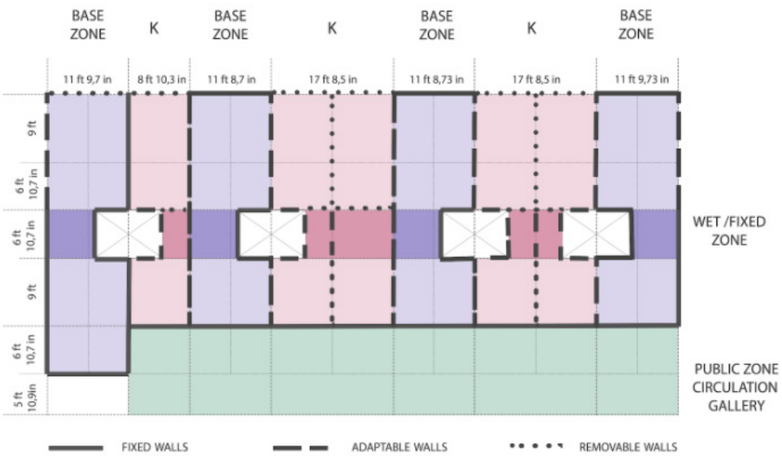


Figure 08: Plant Type of a building where the types of restrictions given by the walls are shown with the defined zones; Source: Team Chile

Engineered Materials and Technologies for Optimal Energy Performance and Comfort

Building envelope. It will be industrially prefabricated and it includes panelized walls to reconfigure the architecture spaces within single-family units, when required. The spatial flexibility is facilitated by the detachable partition system based on a 2D industrialized unitized wall as well as building envelope components (panels) on a 3D Glulam Grid Structure.

Wood as a construction material is lightweight, durable and environmentally friendly. Its composition of cellulose fibers, lignin, hemicellulose and extractables allows it to be resistant and ductile, supporting extreme forces and non-permanent deformations. It contributes to the thermal insulating behavior via its low thermal transmittance, helping to reduce thermal bridges (which are more complex in concrete and steel). However, there are properties that require supplementation, particularly fire protection, acoustic behavior, and thermal inertia or the ability to serve as a heat storage mass to prevent a rapid heating or cooling effect.

The building envelope of our proposal is attached to the timber structure and can be changed over time. It is highly thermal efficient minimizing the losses by conduction and air tightness for infiltrations. The wall panels, from exterior to interior,, have a ventilated layer to avoid overheating. Then, it has layers of insulation composed of wood fiber, continuing with a layer of fiber-cement boards and plasterboard to increase thermal mass. The floor finishing is a concrete slab to increase the thermal inertia. The envelope is considered to be continuously installed on the exterior surface of the structure. A catalogue of variations including the different alternatives of space production will be developed.
Acoustic standards in buildings are a subject of increasing development (Bustos, 2011) due to the growth and activity of cities, which are increasingly noisy places. In Chile, since 2000, following the enactment of the norm(Instituto Nacional de Normalización, 2000), social housing must meet acoustic comfort requirements for comfortable habitability (Ministerio de Vivienda y Urbanismo, 2014). Most are built with perimeter walls of brick and interior walls of wood and with plasterboard and zinc on wood trusses in the roof structure (Ministerio del Medio Ambiente, 2012) establishes maximum permitted noise emission levels (Table 1), identifying defined zones in territorial planning, with zone I corresponding to territories with residential homes.

ZONE Timetables (Hr) 1: 7 a 21 y 2: 21 a 7	1	2
I: It only allows use of residential land, includes public space and / or green area	55	45
II: It also allows the use of zone I, equipment of any scale	60	45
III: In addition to the uses of zone II, productive activities and / or infrastructure	65	50
IV Allows only land uses in productive and / or infrastructure activities	70	70

Table 02. Maximum Sound Pressure Levels (NPS) allowed (Decree 38). (DBA) Source: Supreme Decree No. 38/11 of the Environment. Ministry

Energy saving strategies

This home is a prototype of a flat or apartment unit, and their energy needs are calculated as a single unit home, since this is derivable.

Now, according to the actual location of Casa FENIX 2.0 in Valparaiso, and as a social housing unit, the calculation will be updated. And the strategy of energy saving is related to performance of the house ,and the appliances, and systems included.
The evolution of this home has become a very simple energy need related only to heating, domestic hot water backup , appliances and lighting.
Energy from appliances are very difficult to calculate in a social Chilean housing, since for cooking the main energy source is gas. Nevertheless all appliances are set to be electrical for calculation purposes.

Heating Demand : The heating demand is reduced due to the mild climate condition of Valparaiso.(Csc, Koppen -Geiger classification).
The building envelope, and controlled solar ganis in winter allow a good comfort almost all day, and the need for heating is mainly during nights from May up to September.

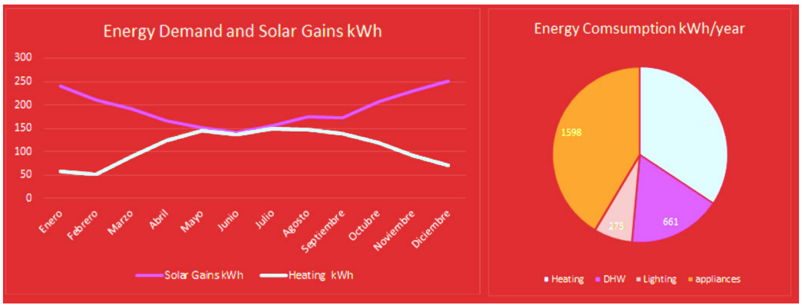


Table 03. Energy Demand monthly

Total Energy Consumption Calculated with Design Builder ®software
Estimated Energy demand on electricity reaches 60kWh/m2 yearly, and this includes radiant heating, DHW (as the backup for solar water heater), Lighting and appliances.
The distribution for energy consumption is in the following pie chart

Solar PV Array

The local proposal uses only electricity as an energy source, coming from the grid connected and from PV array. For this derivable, the PV array has been donated from a local company and the size is according to their possibility.
To meet part of the electrical requirements of the dwelling a 2,6 kWp photovoltaic system. This system will have 6 solar modules 440Wp each, 1 Inverter SMA Schuko 2500W. Also a small battery bank for the contest only , with 200Ah capacity.
The annual energy production is 3.218kWh/year.

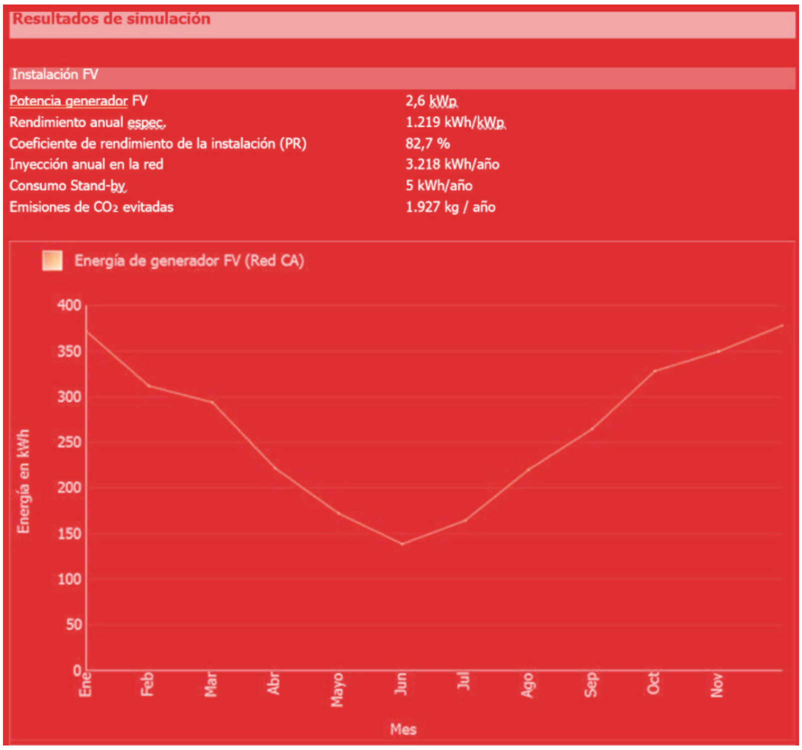


Table 04.This PV system can provide 83.4% of the energy needs of Casa Fenix. PVSol® energy calculation

Figure 09: Picture of heat film; Source: Warmtec.cl

HVAC Heating only
The HVAC heating system is provided by a thin film electric radiant layer under floors which are digitally controlled.

No Active ventilation in this version (as previous ventilation a heat recovery)

Lighting using high efficiency LED luminaries w/ electronic ballast.

Domestic Solar Hot Water System
This includes a thermosiphon solar system w/electric backup , which is donated for the government for social housing. The water capacity is 150Lt.
Calculated DHW coverage (solar fraction) is 80.3% (2.701kWh /year). Electricity needed for the backup is 664kWh/year.(is included in the annual energy consumption) .

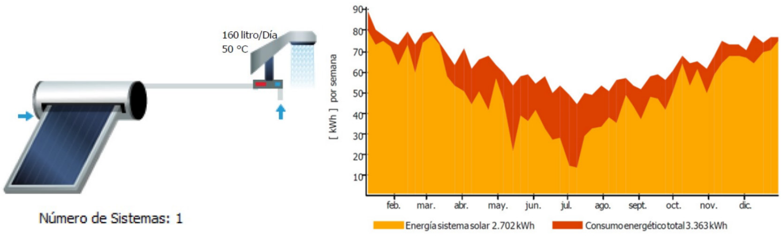


Table 05. Hot water system, TSol ® Software calculation. Energy balance.

Novel Water Treatment System for fire fighting
According to the problem of recurrent fire in this city surrounded by forest, there is a continuous dwelling re-construction in Valparaiso. The hill condition and the steep streets make it difficult for the fire department to reach the fire location on time, and the water on the fire hydrant has no pressure or nor water available. Casa FENIX 2.0 proposes a novel firefighting system, which can use the gray water harvesting of each home to provide enough water as a rapid response in case of fire. The system has 4 parts which are 1, harvesting, 2 natural filter, 3 water tank with a water pump, and 4 , neighbrohood water tank for fire use. as shown in the following figure

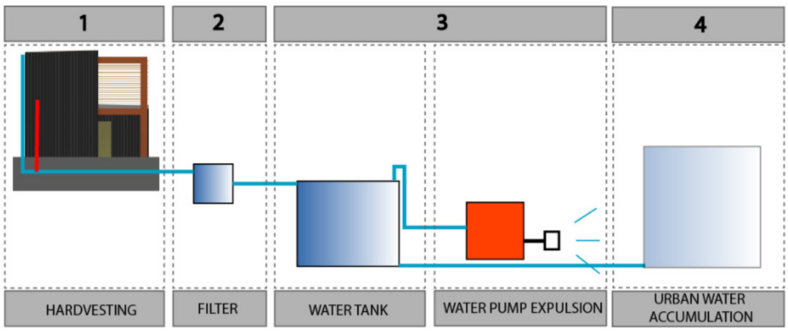


figure 10: Digram system WTS

1. Harvesting:

This will collect grey water from the washing machine, water sinks and shower.

The total water consumption is calculated according to the consumers National Service (SERNAC), in the next chart.

	Utilization	1 Hab	2 Hab	3 Hab
1	Sink	10	20	30
2	Dishwasher	16	32	48
3	Washing Machine	30	60	90
Daily Total (Liters)		106	212	318
Monthly Total (Liters)		3.180	6.360	9.540

Table 6: Calculation of monthly water consumption per inhabitant. Source: Team Chile from data extracted from sernac.cl (SERNAC, 2003)

Three inhabitants in Casa FENIX 2.0 can use 9.540 Lt a month, This means it can harvest 15,6 m3 of grey water annually.

2. Filters: for the pre-treatment system (solids separation), primary treatment (color and odor), secondary treatment (Reed Beds) and tertiary treatment for cloro sanitization. finally to be stored in the main grey water tank Treatment.

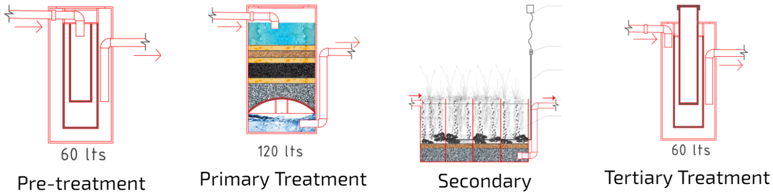


figure 11: Filters pre-treatment system

3. Water Tank and Water Pump Expulsion:
Estanque vertical de polietileno de 2.400 litros Enterrado
1.570 mm de altura
1.640 mm de diámetro

Electrobomba centrífuga de 1 Hp. Caudal máximo de 100 l/min.

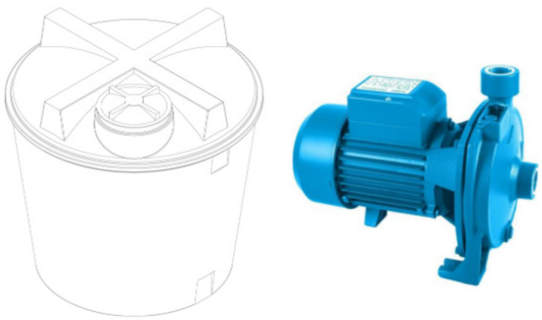


figure 12: Water Tank - Pump Expulsion

4. Urban Water Accumulation: This system collects all the excess water from all neighbrohood . Its considered in local ponds , and also underground water tanks in Valparaiso urban hill system. This allows to fight the fire and also contribute to the urban landscape, allowing green areas and plazas to be irrigated with reusable water.

figure 13: Urban Water Accumulation. Source: Team Chile

Cress Water Solutions. (s.f.). What is a reed-bed or a constructed wetland? Obtenido de https://www.reedbeds.co.uk/page/what-is-a-vertical-flow-reed-bed.php

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